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FINAL TECHNICAL REPORT

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PHASE-DEPENDENT OBSERVATIONS OF INTERMEDIATE POLARS

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This is the Final Technical Report for NASA grant NAG 5-2111, which was awarded to the Space Science Telescope Institute, Baltimore, MD, during the interval 10/1/92 - 3/31/95. The grant supported research that was carried out with NASA's International Ultraviolet Explorer (IUE) satellite. The Principal Investigator was Keith Horne (STScI). Co-Investigators were Jay A. Bookbinder (SAO), Nancy Eaton (Wesleyan) and Phillip J. Martell (STScI). Dr. Howard E. Bond assumed the role of Acting Principal Investigator upon Dr. Horne's departure from STScI in 1994.

The intermediate polars (IPs) constitute a class of cataclysmic variables (CVs), which are binary star systems in which mass is transferred from a late-type main-sequence star to a white dwarf via Roche lobe overflow. In the IPs, the inner accretion disk is evidently disrupted by the magnetic field of the white dwarf. High-temperature shocks at the white dwarf's magnetic poles (where accretion occurs) produce X-rays, which are reprocessed into photons over a broad energy band across the electromagnetic spectrum. Because the white dwarf typically spins rapidly (rotation periods a few 10s to a few 100s of seconds), the signals due to both the X-rays and reprocessed photons are pulsed. The shape of the spectrum of pulse amplitude as a function of wavelength yields information about both the temperature and size of the pulse-emitting region. It has been noted by several investigators that the optical pulsation amplitudes rise steeply toward short wavelengths. It is therefore a fair surmise that pulsation amplitudes peak in the ultraviolet.

The scientific goal of this project was to observe a representative sample of IPs, using IUE, in search of the expected strong UV pulsations, and hence to further our understanding of pulse-producing mechanisms. We observed FO Aqr over two contiguous IUE shifts on 22-23 October 1992; EX Hya over two contiguous IUE shifts on 11 May 1993; AO Psc over 4 IUE shifts on 26-27 June 1994; and V1223 Sgr and FO Aqr over 4 IUE shifts on 7-9 October 1994.

For FO Aqr, we used a multiple-exposure technique, in which repeated exposures were made at fixed spin phase at each of four pre-determined offsets in a single IUE SWP image. This method was necessitated by the need for good time-resolution of the 20.9 minute pulsation period. (The IUE signal-to-noise ratio (S/N) is very low for short exposures of our relatively dim ($V \sim 13.5$) target.) We repeated this procedure on a second SWP image, yielding spectra time-resolved into 8 spin-phase bins. For purposes of extracting these multiple exposure images, we also observed a hot white dwarf (G191-B2B) in order to map the SWP point-spread function (PSF) at each wavelength. In addition, we made one 1254-second LWP exposure of FO Aqr.

For the slower pulsations of EX Hya, we took a series of short ($\sim$13.5 min) SWP exposures (at least two per IUE image) in order to overcome as best we could sampling problems caused by the near 3/2 resonance between orbit (98 min) and spin (67 min) periods. A total of 9 SWP images of EX Hya were obtained. In addition, we obtained one 20 minute LWP exposure of EX Hya and three 13.5 minute exposures (on a single image) of a nearby hot white dwarf.

The basic method of multiple exposures synchronized with the spin period, used earlier for the FO Aqr observations, was repeated for the AO Psc, V1223 Sgr and second FO Aqr observations, except that in this case we exposed at three offsets on each image (thus resolving the spin pulse into 9 bins). We obtained 3 SWP images of AO Psc; 3 SWP images of V1223 Sgr; 3 LWP images of AO Psc; and 3 LWP images of FO Aqr. We observed a hot subdwarf (BD +28°4211) in order to again establish the psf across each image.

A visual survey of the IUE images shows evidence of continuum and emission-line pulsations. To quantify these detections, Dr. Martell has written computer software for extraction of spectra from the multiple-exposure images. The software appears to satisfactorily extract spectra from the images, and we have found large pulse-phased modulations in both the continuum and emission lines of AO Psc. The work is now being continued and prepared for publication.

PATENT/INVENTION REPORT

Principal Investigator: Dr. Howard Bond

Grant : NAG5-2111

Patents/Inventions Developed: NONE

EQUIPMENT AND PROPERTY INVENTORY REPORT

Principal Investigator: Dr. Howard Bond

Grant : NAG5-2111

Equipment/Property Purchased: NONE

FINAL PERFORMANCE REPORT

Grant Number: NAG5-2111
Grant Titles: *The Broad Emission and Absorption Line Region in NGC 3516*
PI: Dr. Anuradha Koratkar
Institution: Space Telescope Science Institute
Grant Period: 10/15/92 - 07/31/96

Data Reduction: Phase Complete

Spectral Fitting: Phase Complete

Analysis: Data Analysis Phase Complete
Simulations of physical Models complete.

A paper has been written for this analysis and published in the Astrophysical journal. Its title and abstract are given below. The published paper is also attached.

TITLE:

The Disappearing Broad Absorption Lines and Variable Emission Lines in NGC 3516

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ABSTRACT:

The Seyfert 1 galaxy NGC 3516 was monitored during 1993 February 16 - May 13 by IUE every 4 days for the first month and then every 2 days for 2 months giving a total of 40 observations. This paper gives the initial results from this campaign.

(1) The broad C IV 1549 emission line variations are delayed relative to those of the ionizing continuum by ~4.5$days, consistent with that of other similar luminosity AGN.

(2) The mean 1993 UV continuum level was about a factor of three higher than the mean archive spectrum, and was at a record level throughout the campaign.

(3) There was dramatic variability in the CIV 1549 line profile when compared to the IUE archival data. A narrow absorption line is present in all the 1993 spectra. In contrast, the broad variable trough was undetectable, whereas it is a very strong feature in all of the IUE archival spectra. The NV 1240 and SiIV 1400 lines showed a similar behaviour.

A variable broad absorption line (VAL) model is required to explain the archival data, but it is unclear if a VAL model alone can explain the 1993 IUE data. Photoionization models suggest that the lack of line troughs in 1993 cannot be caused simply by increased ionization of the VAL gas. We propose two distinct models to explain the 1993 spectra: either the VAL gas has been dissipated, leaving a narrow absorption line presumably due to a more distant absorber, or an emission component, possibly a bi-cone, has greatly increased it's contribution to the blue wing. Dissipation of the VAL gas implies a dynamic absorber, possibly the ionized surface layer of a molecular torus. An extra emission component implies that the BLR properties in NGC 3516 may be radically different than has hitherto been proposed.

THE ASTROPHYSICAL JOURNAL, 470:378–393, 1996 October 10

NAG5-2111

THE DISAPPEARING BROAD ABSORPTION LINES AND VARIABLE EMISSION LINES IN NGC 3516

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ABSTRACT

The Seyfert 1 galaxy NGC 3516 was monitored during 1993 February 16–May 13 by *IUE* every 4 days for the first month, and then every 2 days for 2 months giving a total of 40 observations. This paper gives the initial results from this campaign. (1) The broad C IV $\lambda1549$ emission line variations are delayed relative to those of the ionizing continuum by ~4.5 days, consistent with that of other similar luminosity active galactic nuclei. (2) The mean 1993 UV continuum level was about a factor of 3 higher than the mean archive spectrum and was at a record level throughout the campaign. (3) There was dramatic variability in the C IV $\lambda1549$ line profile when compared to the *IUE* archival data. A narrow absorption line is present in all of the 1993 spectra. In contrast, the broad variable trough was undetectable, whereas it is a very strong feature in all of the *IUE* archival spectra. The N V $\lambda1240$ and Si IV $\lambda1400$ lines showed a similar behavior.

A variable broad absorption line (VAL) model is required to explain the archival data, but it is unclear if a VAL model alone can explain the 1993 *IUE* data. Photoionization models suggest that the lack of line troughs in 1993 cannot be caused simply by increased ionization of the VAL gas. We propose two distinct models to explain the 1993 spectra: either the VAL gas has been dissipated, leaving a narrow absorption line presumably due to a more distant absorber, or an emission component, possibly a bicone, has greatly increased its contribution to the blue wing. Dissipation of the VAL gas implies a dynamic absorber, possibly the ionized surface layer of a molecular torus. An extra emission component implies that the broad line region properties in NGC 3516 may be radically different than has hitherto been proposed.

Subject headings: galaxies: active — galaxies: individual (NGC 3516) — galaxies: Seyfert — ultraviolet: galaxies

1. INTRODUCTION

One of the central problems in the field of active galactic nuclei (AGNs) research is to understand the nature of the broad line region (BLR). Over the past decade it has become clear that monitoring the response of the emission line gas to ionizing continuum variations is a very powerful method for determining the size, structure, and kinematics of the BLR (see Peterson 1993 for a review). Broad emission line variability occurs in AGNs covering a wide range in luminosity. The emission line variations are delayed relative to those of the continuum by characteristic timescales which range from a few months in high-luminosity quasars (O'Brien & Harries 1991) down to a few days in low-luminosity Seyfert 1 galaxies (Clavel et al. 1990, 1991; Koratkar & Gaskell 1991a, 1991b; Korista et al. 1995). These time delays, or lags, are usually interpreted in terms of the time-delayed response of the spatially extended BLR to the ionizing continuum source (Peterson 1993).

About 10% of all QSOs are broad absorption line (BAL) QSOs, in that in addition to broad emission lines, they have broad absorption lines blueward of line center (extending to -10^4 km s^{-1}) with large equivalent widths (typically 40 Å for C IV) that appear to be intrinsic to the nucleus. In most other respects the BAL QSOs appear to be normal (see Weymann et al. 1991). The precise relationship between the

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emission and absorption line gas is unclear. However, there is mounting evidence that most, and possibly all, radio-quiet QSOs have BAL gas with a small covering factor (Weymann et al. 1991; Stocke et al. 1992; Hamann et al. 1993). About 3% of Seyfert 1 galaxies observed with *IUE* show similar line profiles, suggesting the existence of similar, although somewhat narrower, broad absorption troughs. These features are also blueshifted (extending to ~ -3000 km s^{-1}) and have equivalent widths in the range 4–10 Å (Ulrich 1988). The relationship between these two types of AGN and between the emission and absorption line regions in general is unclear, but the Seyfert galaxies with absorption features may be a low-luminosity manifestation of the BAL QSO phenomenon (Shull & Sachs 1993). Since Seyfert 1 galaxies are believed to be the low-luminosity analogs of QSOs, the study of these objects should provide information on the physical properties of the emission and absorption line regions in AGN.

Only three Seyfert 1 galaxies believed to exhibit variable absorption features have been studied in any detail in the UV, and the true nature of the absorbing gas remains elusive. For NGC 4151 the absorbing gas seems to consist of a large number of high-density ($>10^9$ cm^{-3}) optically thin clouds, lying just outside the BLR (Bromage et al. 1985; Kriss et al. 1992)—properties similar to those derived for BAL QSOs (Korista et al. 1992).

For NGC 5548, Shull & Sachs (1993) assuming that C IV was the dominant stage of ionization, used UV observations to deduce that the absorption was produced by optically thin, weakly ionized ($U \sim 10^{-3}$), low-density ($n_e \geq 5 \times 10^5$ cm^{-3}) clouds, located outside ($r \sim 14$ pc) and partially obscuring the BLR. Combined with the lack of Mg II and Lyα absorption they placed an upper limit on the column density of $N_H < 10^{20.5}$ cm^{-2}. Mathur et al. (1995) in an attempt at linking the X-ray and UV absorbers into a single coherent model, combined X-ray observations of O VII and O VIII absorption edges (Fabian et al. 1994) with the UV observations to deduce that the absorption arises in highly ionized ($2.2 < U < 2.8$), high column density $n_H = 3.8 \times 10^{21}$ cm^{-2} clouds located at a distance of between 8 light-days and one light-year from the ionizing continuum source. The detection of Lyα absorption in the 1993 *HST* spectra of NGC 5548, and in a reanalysis of the archival *IUE* data allowed them to place limits on the H I column of 10^{13} cm^{-2} $< N_{H\,I} < 10^{18}$ cm^{-2}. Although their results are consistent with the observed anticorrelation in the EW (C IV) with the continuum at λ1750 Å, their "single-cloud" model underestimates the observed Fe K emission by a factor of 25. This suggests that either the link between the UV and X-ray absorbers is rather tenuous or that a "single-cloud" model for the absorbing gas is inappropriate.

For NGC 3516 the situation, as summarized below, is far less clear (Voit, Shull, & Begelman 1987; Walter et al. 1990; Kolman et al. 1993). Ulrich (1988) noted that NGC 3516 has the strongest (largest equivalent-width) and most variable ultraviolet absorption line spectrum of the Seyfert 1 galaxies observed by *IUE*, making it a key test-case for AGN models.

The variability of NGC 3516 in the optical, UV and X-rays has been previously reported by Ulrich & Boisson (1983); Voit et al. (1987); Walter et al. (1990); Bochkarev, Shapovalova, & Zherov (1990); Krupper, Urry, & Canizares (1990); and Kolman et al. (1993). The UV continuum in NGC 3516 has varied by a factor of 4 in the *IUE* archival data. Both the broad emission and absorption lines vary on timescales of a few days to weeks, with significant variations seen on 2 consecutive days of observations. Walter et al. find that the intensity of the broad base of the C IV emission line correlates very well with the UV continuum, whereas the narrow emission core varies little if any. They also find that the C IV absorption line can be represented by a narrow stable component and a variable broad absorption line (VAL).

As part of its AGN BLR monitoring campaign, the European "LAG" collaboration observed NGC 3516 at 22 epochs between 1990 January and June using the 2.5 m Isaac Newton and the 4.2 m William Herschell telescopes on La Palma (Wanders et al. 1993). Significant optical continuum and Balmer line variability occurred on timescales as short as the minimum sampling interval of 2–3 days. The cross-correlation functions indicate a small BLR size of about 14 and 11 light-days for Hα and Hβ, respectively, which is somewhat smaller than the 25 light-days derived by Cherepashchuck & Lyutyi (1973). The quality of the LAG dataset is good enough to detect fairly small line profile variations. On the shortest observed timescales, symmetric variations occurred across the entire line profile. However, on timescales of a few weeks, asymmetric profile changes occurred, with significantly more variability in the blue compared to the red wing (Wanders et al. 1993; Wanders & Horne 1994). Although, Hα and Hβ appear to vary in a similar fashion overall, there were some detailed differences. In particular, a dip in the Hβ profile which formed during the LAG campaign was not seen in Hα, even after allowing for contamination by narrow [N II] λ6548 (Wanders et al. 1993). The Hβ dip coincides in velocity (-1300 km s^{-1}) with that of the UV absorption lines seen in the archival *IUE* data. Unfortunately there were no UV spectra of NGC 3516 taken during the LAG campaign for comparison.

A response function analysis of the LAG campaign Hα data (Wanders & Horne 1994) suggests that either the Balmer line emitting BLR geometry of this object is non-spherical or that the continuum and/or line emission is highly anisotropic. Wanders & Horne (1994) also find that the Hα response function is nonstationary, most likely due to variations in the spectral energy distribution, nonlinear line response, cloud destruction/formation or time-dependent variations in the source anisotropy. The velocity resolved Hα response function shows a similar structure across a broad range in velocity space, ruling out radial motion as dominating the Balmer line emitting gas kinematics in NGC 3516.

Although the archival *IUE* data and the optical data showed that variability occurs in NGC 3516 on timescales of less than a few weeks, we were severely hampered in our understanding of the emission and absorption line regions in this AGN due to the lack of a well sampled UV data set. To better constrain the emission line properties (e.g., the size of the BLR and the gas kinematics), and the properties of the absorption line region (e.g., cloud density and size, viability of the Walter et al. [1990] absorbing cloud model), we organized an intensive *IUE* monitoring campaign during 1993. The principal objectives of the campaign were as follows: (1) determine the structure of the broad emission line region, and compare it to other AGNs; (2) determine the origin of the broad trough in the C IV line (i.e., is it due to absorption or just a lack of emission); and (3) determine

TABLE 1

NEW *IUE* OBSERVATIONS OF NGC 3516

Image Number	UT Date (month/day/year)	UT Start (hour: minute: second)	Julian Date (2440000+)	Duration (minutes)	Notes
SWP 46972......	02/16/93	14:21:11	9035.098	210	
LWP 24932......	02/16/93	19:16:54	9035.304	70	a
SWP 47009......	02/20/93	13:59:36	9039.083	145	
SWP 47043......	02/24/93	14:22:07	9043.099	107	
SWP 47072......	02/28/93	06:26:14	9046.768	240	
SWP 47092......	03/04/93	04:09:57	9050.674	125	
SWP 47127......	03/06/93	09:11:69	9052.884	69	
SWP 47241......	03/10/93	08:58:42	9056.873	85	
SWP 47266......	03/12/93	07:49:46	9058.827	120	
SWP 47275......	03/14/93	07:56:52	9060.832	115	
SWP 47325......	03/20/93	15:47:56	9067.158	90	
SWP 47334......	03/22/93	15:36:49	9069.151	80	
SWP 47350......	03/24/93	16:07:02	9071.172	98	b
SWP 47365......	03/26/93	15:29:13	9073.146	110	
SWP 47381......	03/28/93	15:04:25	9075.128	175	
SWP 47392......	03/30/93	22:41:13	9077.445	195	
SWP 47401......	04/01/93	13:56:03	9079.081	180	
LWP 25251......	04/01/93	17:43:54	9079.239	60	c
SWP 47413......	04/03/93	17:36:03	9081.233	120	
SWP 47433......	04/07/93	02:01:14	9084.584	160	
SWP 47449......	04/09/93	06:02:25	9086.751	135	
SWP 47460......	04/11/93	07:14:13	9088.802	65	
SWP 47475......	04/13/93	06:00:00	9090.750	130	
SWP 47489......	04/15/93	13:44:48	9093.073	130	
SWP 47497......	04/17/93	14:18:52	9095.097	100	
SWP 47506......	04/19/93	13:35:48	9097.067	140	
SWP 47518......	04/21/93	13:51:51	9099.078	155	
SWP 47533......	04/23/93	13:36:09	9101.067	160	
SWP 47545......	04/25/93	13:42:14	9103.071	160	
SWP 47558......	04/27/93	13:14:38	9105.052	180	
SWP 47569......	04/29/93	13:11:32	9107.050	175	
SWP 47578......	05/01/93	12:17:50	9109.013	105	
SWP 47596......	05/03/93	13:49:34	9111.076	4	d
SWP 47605......	05/04/93	20:14:52	9112.344	105	
SWP 47607......	05/05/93	05:30:48	9112.729	20	e
SWP 47617......	05/06/93	23:55:02	9114.496	165	
SWP 47628......	05/09/93	00:11:32	9116.508	145	
SWP 47642......	05/11/93	03:59:56	9118.667	140	c
SWP 47656......	05/12/93	04:04:32	9119.670	140	
SWP 47661......	05/13/93	04:39:15	9120.694	95	

[a] Mg II overexposed.
[b] Blank exposure. Target not in aperture due to anomaly.
[c] Error = 9".5 in X direction for one 40 minute segment.
[d] Very weak exposure. Cosmic-ray hit at C III].
[e] Very weak exposure. Contaminated by guide star.

no systematic disagreement in extracted net fluxes between the two techniques (Kinney et al. 1991).

To allow for drifts in the spatial direction due to the gyro guiding, and hence maintain photometric accuracy, the spectra were extracted using the 15 line optimal extraction routine rather than the standard 9 line extraction. The extracted net fluxes were converted to absolute fluxes using the *IUE* calibration of Bohlin et al. (1990). A correction was made for the SWP sensitivity degradation (Bohlin & Grillmair 1988), as updated through 1992.5 by R. C. Bohlin (1995, private communication). The linear extrapolation to 1993 epochs should not cause absolute flux errors of more than 1%. The LWP sensitivity degradation was similarly corrected for using data extrapolated from Teays & Garhart (1990). The use of segmented exposures did result in less on-target exposure time, and hence a lower exposure level than originally desired, although this was partly compensated for by the optimal extraction procedure. The broader spatial PSF potentially introduces more fixed-pattern noise, which is hard to estimate.

2.4. *Flux Measurements and Spectral Fitting*

As it is difficult to isolate the C IV emission line component in NGC 3516 due to the presence of the absorption line, the C IV flux during the campaign was simply measured by integrating above an eye estimated straight line fit to continuum windows located either side of the line.

The observed line fluxes at each epoch are given in Table 2, and refer to a rest-frame wavelength interval of 1500–1600 Å. The observed continuum fluxes at 1450 Å (rest-frame) are also given in Table 2, and both are plotted on a relative flux scale in Figure 1. This technique clearly measures only the change in the total C IV flux, and does not indicate any relative change between the absorption and emission line components.

To investigate the long term nuclear variability of NGC 3516, we have also included the archival *IUE* spectra in our analysis. A few archival spectra were unavailable for reextraction, but their omission does not affect our conclusions. The archival spectra were extracted and flux calibrated as

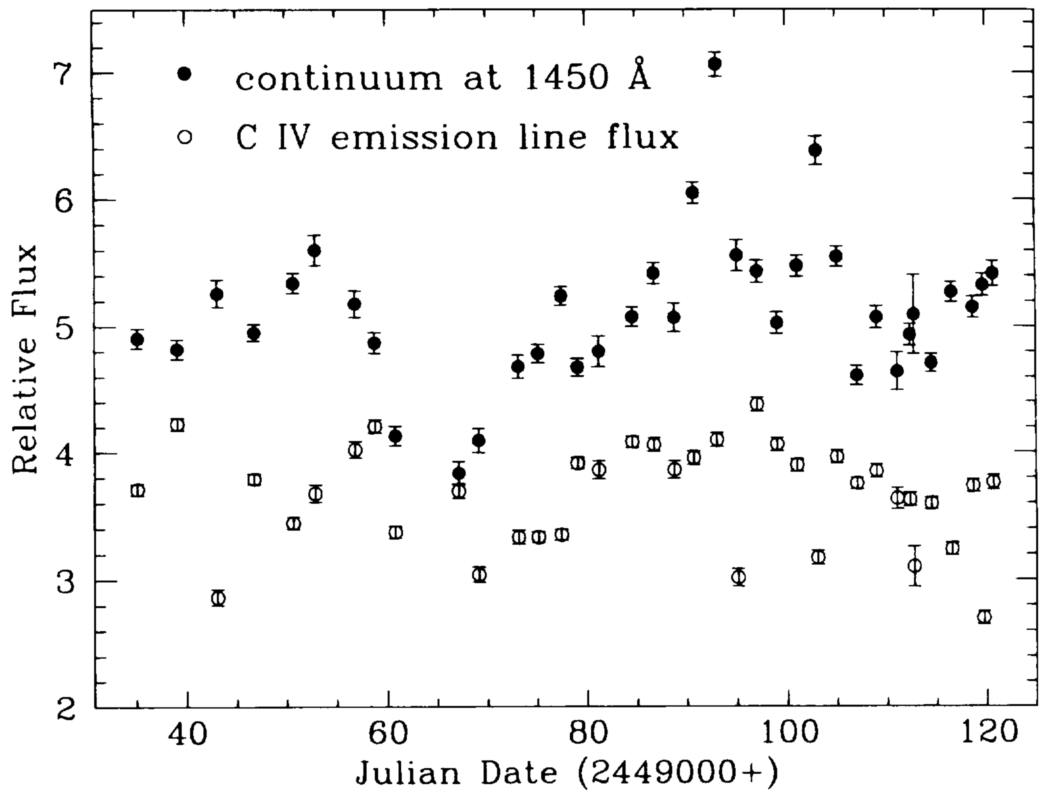

FIG. 1.—Time series for the continuum (*filled circles*) and the C IV line flux data (*open circles*) for the 1993 monitoring data. The continuum flux is in units of 10^{-14} erg cm^{-2} s^{-1} Å^{-1}, while the line flux is in units of 10^{-12} erg cm^{-2} s^{-1}. The continuum varied by $\pm 25\%$ and the C IV line flux varied by $\pm 15\%$ peak to peak.

frame, and include contributions from N IV] λ1486, O III] λ1663, and Si III] λ1893, respectively. The Si IV/O IV] blend was measured between 1370 and 1440 Å. The Mg II λ2798 line flux (measured between 2725 and 2915 Å observed frame) is particularly difficult to measure given the uncertainty in continuum placement and may include a contribution from Fe II emission (§ 3.2). N V emission-line measurements are not included as this line is heavily blended with both Lyα and geocoronal Lyα emission and also exhibits a superposed N V absorption line. The errors in the emission-line fluxes and line equivalent widths were determined by disturbing the continuum fits by $\pm 5\%$ for the noisier spectra (i.e., the archival-low and archival-medium spectra) and by $\pm 3\%$ for the others. This is consistent with the root mean square variation in the continuum flux over the wavelength regions used in the determination of the continuum fits.

The C IV and Si IV absorption line equivalent widths were measured relative to a straight line drawn between the adjacent emission-line peaks. The N V absorption was measured relative to a horizontal line defined by the red emission-peak. Although physically distinct broad and narrow absorption components may exist in the archival data we have made no attempt at deblending them. Note that we do not give errors for the absorption line equivalent widths, as we consider measurement of absorption relative to some imposed line profile highly suspect based on the observed line profile variability (§ 3.2). In general however, we assume that the given values are lower limits to the true absorption.

TABLE 3
ARCHIVAL *IUE* SWP OBSERVATIONS OF NGC 3516

Archival-low	Archival-mid	Archival-high
SWP 01821	SWP 08633	SWP 24192
SWP 01840	SWP 08883	SWP 32273
SWP 06921	SWP 13425	SWP 32280
SWP 19948	SWP 14241	SWP 37274
SWP 19957	SWP 14243	SWP 37375
SWP 26811	SWP 19940	SWP 37293
SWP 26923	SWP 21257	SWP 37308
SWP 35947	SWP 24253	SWP 37327
	SWP 24344	
	SWP 24391	
	SWP 26872	
	SWP 29334	
	SWP 29340	
	SWP 30886	
	SWP 30891	
	SWP 33199	
	SWP 33203	
	SWP 33204	
	SWP 35946	

TABLE 4
ARCHIVAL *IUE* LWP OBSERVATIONS OF NGC 3516

Archival-low	Archival-mid	Archival-high
LWP 06831	LWP 02019	LWP 12042
LWP 06897	LWP 06858	LWP 12049
	LWP 09213	LWP 16524
	LWP 09215	LWP 16548
	LWP 10671	LWP 16567
	LWP 10678	

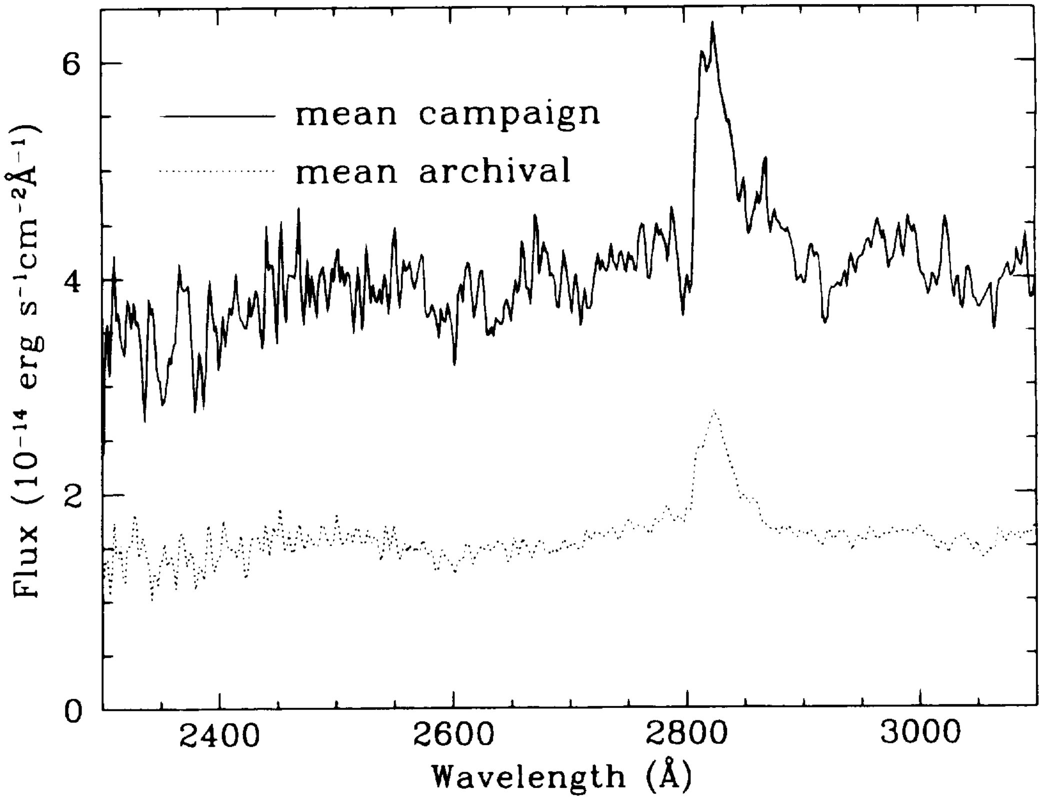

FIG. 3a

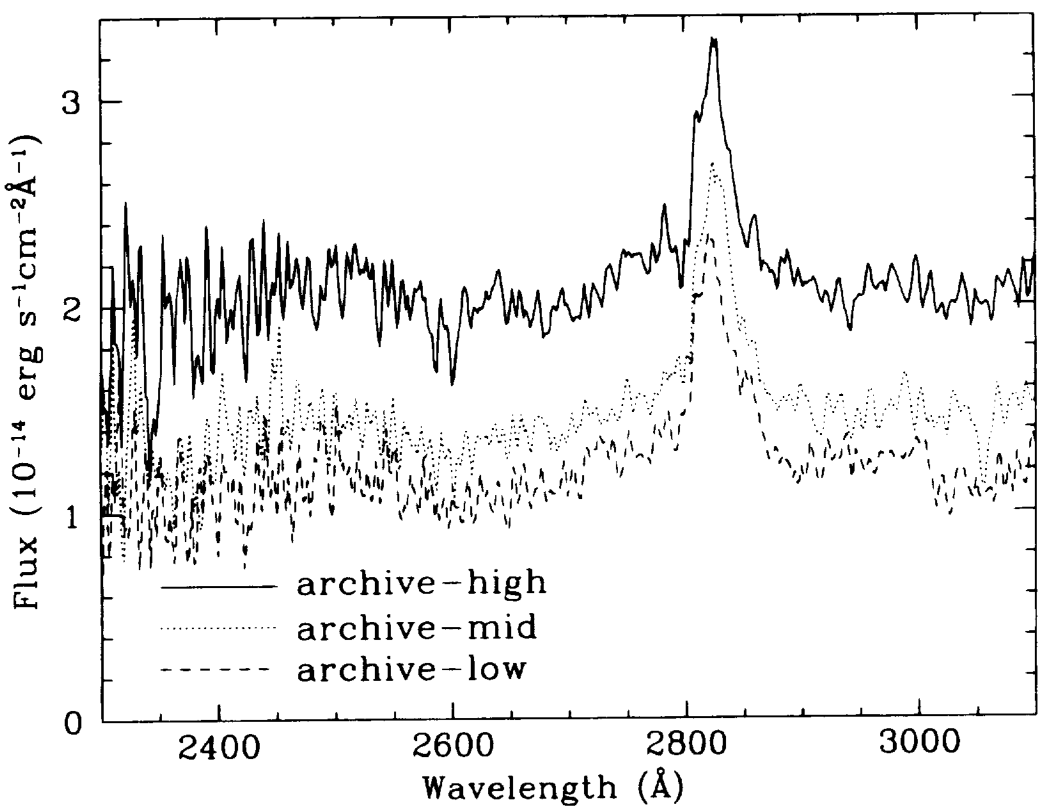

FIG. 3b

FIG. 3.—(a) Comparison of the mean archival and campaign spectra for Mg II. (b) A comparison of the archival-low, archival-medium, and archival-high state spectra for Mg II. As for C IV, the Mg II emission line is generally stronger when the continuum is brighter.

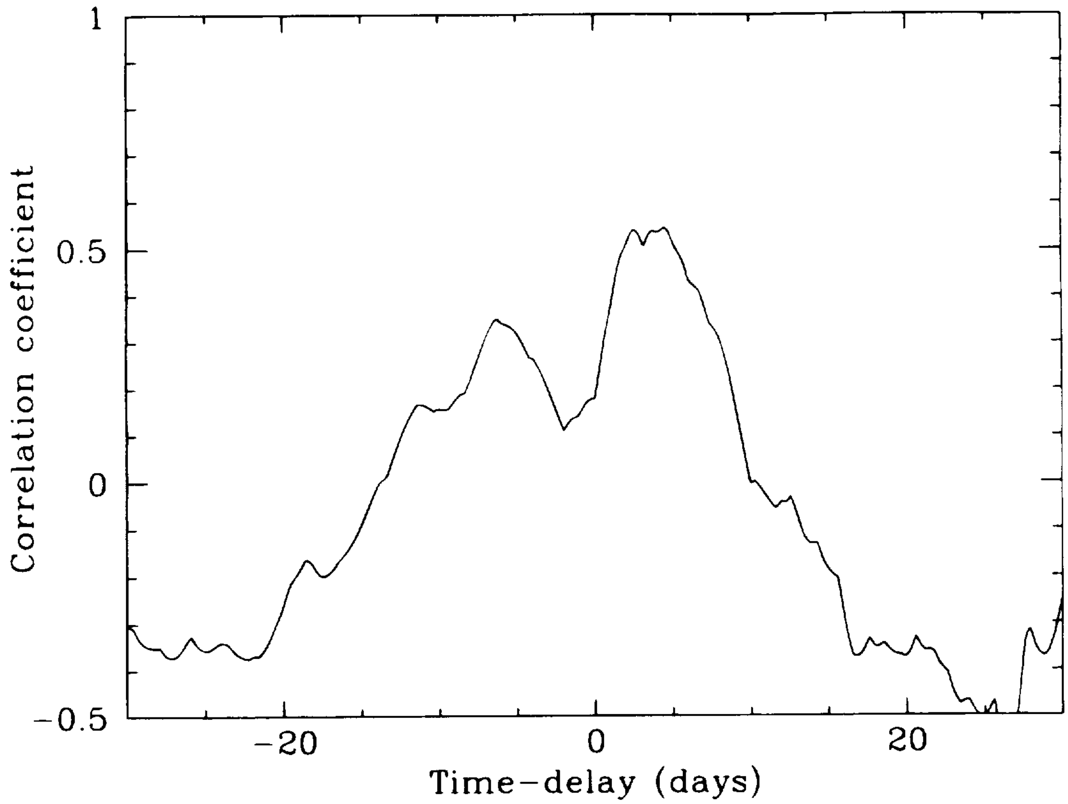

FIG. 4*a*

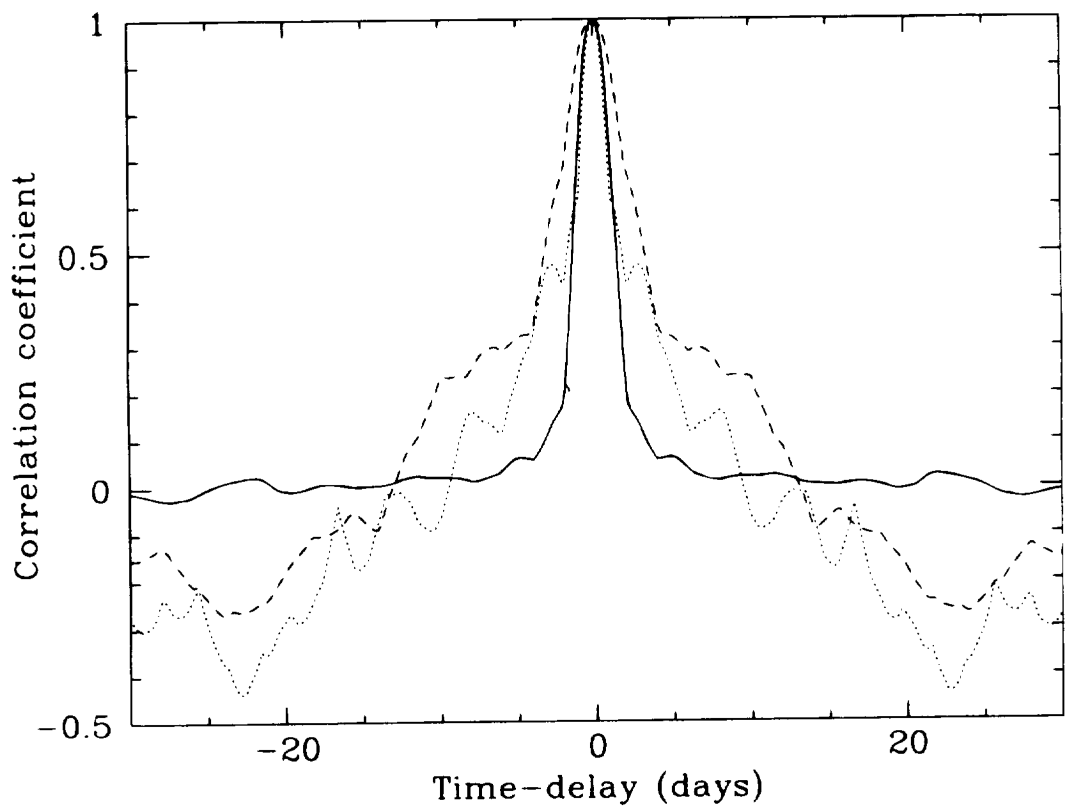

FIG. 4*b*

FIG. 4.—(*a*) Cross-correlation function (CCF) determined from all the *IUE* data on NGC 3516 (*solid line*). (*b*) Comparison of the sampling window (*solid line*) with the continuum autocorrelation function (ACF; *dashed line*) and the C IV emission line ACF (*dotted line*).

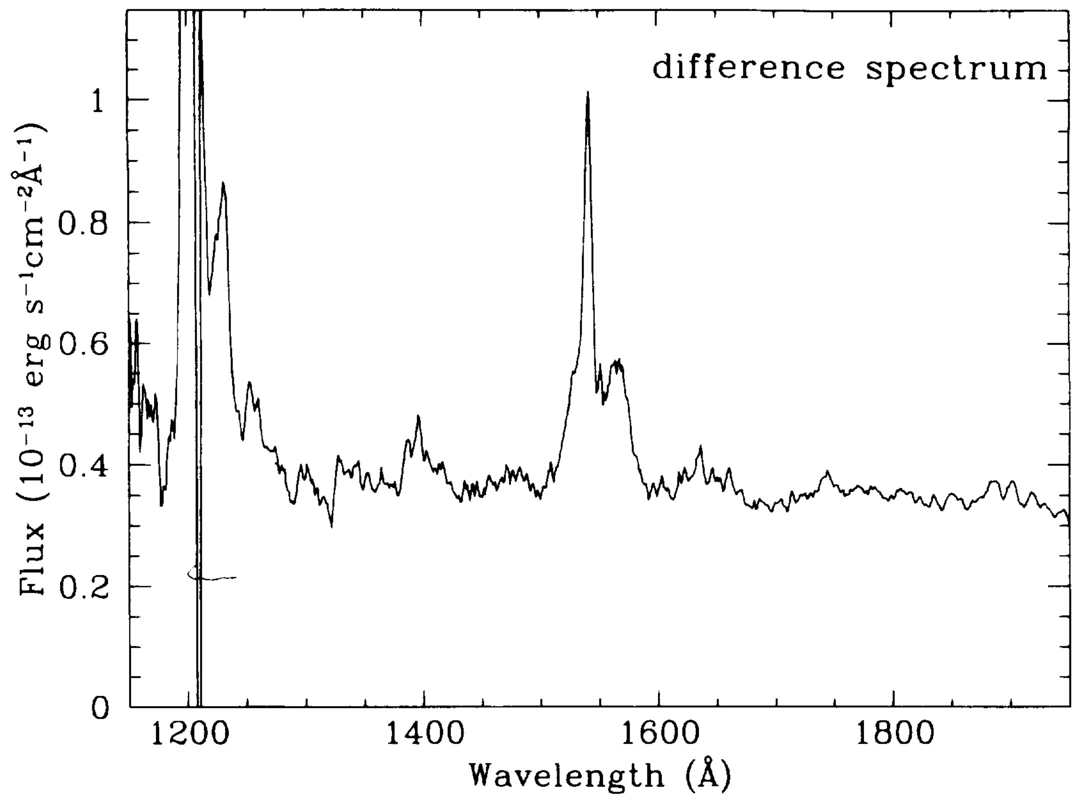

FIG. 5.—Difference between the campaign and mean archival spectra (campaign—mean archival) for C IV. The difference spectrum shows a clear deficit of response redward of line center.

appears to saturate more slowly than the blue C IV wing, but does saturate above the high continuum level. The lower $\eta(v)$ in the red C IV line core may be due to dilution by narrow line emission/absorption or a lack of variable emission (§ 4.3). Figure 6*e*, which shows the $\eta(v)$ formed between the mean campaign and mean archival spectra, indicates that on average, the main difference in response between the campaign and archival data is an increased response over a narrow range in velocity space (~ 3000 km s^{-1}) centered ~ 1500 km s^{-1} blueward of line center.

The N V blue wing is badly blended with Lyα, but the red wing appears to vary in a similar way to He II. At low continuum levels N V is weak, with $\eta \sim 1$, declining to ~ 0.6 at high continuum levels. In contrast to C IV, $\eta \sim 0.13$ for C III] at all continuum levels. The Si IV, O IV] blend is weak and badly affected by absorption at low to medium continuum levels, but we estimate $\eta < 1$ at high continuum levels. Given the uncertainty in continuum placement, the Mg II responsivity is low for the archival LWP data. The Mg II line appears much stronger in the two campaign LWP spectra (Fig. 3*a*), implying $\eta \sim 0.6$ at high continuum levels. However, the extra emission appears mainly in the red wing of Mg II and may be due to an increase in Fe II emission. Several other weak emission features are seen in the campaign data at wavelengths corresponding to expected Fe II lines (Grandi 1981).

Galactic Mg II absorption can clearly be seen in the blue wing of Mg II in the LWP campaign and archival-high spectra. Similarly, galactic absorption lines with EWs of ~ 0.5 Å can be seen in the mean campaign spectrum at 1302 and 1334 Å. Kolman et al. (1993) suggest that the slightly asymmetric shape of the Mg II line at some epochs may be due to a weak low-ionization VAL. However, given the shape of the C IV line in the campaign data and the suggested Fe II emission, we find no convincing evidence for a Mg II VAL at any continuum level. Higher spectral resolution data are required to confirm this conclusion. There is also no evidence for a narrow intrinsic Mg II absorption line at the same redshift as in C IV.

Based on the BLR models discussed by Goad et al. (1993, 1994), the observed combination of low responsivity and the declining reprocessing efficiency at higher continuum levels are consistent with models in which the emission line gas has both a low optical depth at the Lyman limit and a high ionization parameter. This conclusion is consistent with the suggestion of optically thin gas to explain the comparative widths of the C IV and continuum ACFs (§ 3.1) and the low C III]/C IV emission line ratio.

4. VARIABLE BROAD ABSORPTION OR A PREFERRED BLR GEOMETRY?

The profile variations observed in NGC 3516 have been discussed previously mainly in terms of a VAL (§ 4.1). Although we consider this model to be the most likely, we also note another possibility, namely that the broad absorption troughs may have been "filled in" during the campaign by an additional emission component (§ 4.2). This additional emission component cannot alone explain the profile variability seen in *IUE* archival data, and does not remove the need for a VAL, but may indicate a preferred BLR geometry and velocity field for the line-emitting gas in this object. The merits of each of these models are discussed below.

species which are merely trace fractions in gas far more highly ionized ($U \sim 1$) than is usually assumed for the BAL QSOs (Mathur et al. 1994, 1995). In these models the decrease in fractional abundance for species such as C^{+3} and N^{+4} could be large for small changes in U. Soft X-ray observations suggest NGC 3516 contains a warm absorber (Kolman et al. 1993) consistent with the UV absorption, but the small observed variations in the VAL equivalent widths and strong low ionization Si^{+3} absorption seen in the archival data argue against such a highly ionized model. We therefore conclude that, in the context of a VAL model, the most likely cause for the reduction in VAL strength in the campaign data is due to dissipation or bulk motion of the absorbing gas away from the line of sight. This supports the conclusions drawn by Walter et al. (1990), concerning bulk motions of the absorbing gas, and indicates that the VAL region in NGC 3516 is highly dynamic.

Since we have no information concerning the short-term variability of the absorbing gas (due to averaging of the archival and campaign spectra), we cannot easily constrain the density of the absorber and thus its size. If the density estimates of Walter et al. are correct ($N_e \sim 10^5$ cm^{-3}), then together with the absence of a Mg II VAL, which places an upper limit on the hydrogen column density of $N_{\rm H} < 10^{20.5}$ cm^{-2}, an upper limit on the absorbing cloud size of less than 10^{15} cm can be derived. For transverse cloud velocities of ~ 1500 km s^{-1} the crossing time for the absorber is ~ 2–3 months. Clouds moving obliquely across our line of sight may persist for much longer periods ($\sim$years). The elapsed time between the last of the archival observations and the beginning of the campaign, is in this instance large enough for the absorber to have moved out of our line of sight.

The available data for NGC 3516 do not allow us to determine the exact nature of the VAL. For example, whether it comprises a set of clouds along the line of sight or a wind. Neither do the data accurately locate the VAL relative to the BLR. The fact that the troughs are clearly deeper than the continuum level (e.g., N V in the archival-high spectrum; see Fig. 2*b*) implies that at least some of the absorbing gas covers the BLR. This could be due merely to the narrow absorption component present in the campaign data and previously inferred by Walter et al. (1990), but Walter et al. find their spectral fits require the VAL to at least partially cover the BLR. If we assume the VAL gas originates outside the BLR, then a possible location is the fragmenting surface of a surrounding molecular torus (Heckman et al. 1989; Weymann et al. 1991; Kolman et al. 1993). Although we are not viewing the central continuum source and BLR of NGC 3516 through the entire torus, if our line of sight skims its surface, we may see absorption due to a wind and/or cloud fragments ablated off of the torus. As this situation is intrinsically highly dynamic, variations in the amount of absorber along the line of sight are not unexpected. The complex extended narrow-line region and radio structure of NGC 3516 imply we are viewing this object at a large angle from the radio axis (Goad & Gallagher 1987; Miyaji, Wilson, & Perez-Fournon 1992). Interestingly, the extended structure shows several " blobs " of emission, and Miyaji et al. suggest NGC 3516 may undergo sporadic ejection of material. Although this material is being ejected along a different direction to the UV absorber, it may be related and further indicates the dynamic nature of NGC 3516.

4.2. *A Preferred BLR Geometry—Evidence for a Biconical Outflow?*

A comparison of the campaign and archival spectra with previously published BLR models (see Pérez, Robinson, & de la Fuente 1992; O'Brien, Goad, & Gondhalekar 1994; Robinson 1995) suggests that at least in a qualitative sense the observed C IV emission line profile variation seen in NGC 3516 in 1993 is consistent with emission from a biconical BLR or a beamed continuum source. Such a model has been proposed recently to explain the C IV emission line variability in NGC 5548 (Wanders et al. 1995).

A biconical model cannot however explain the archival data on its own. For example, the extension of the N V line trough below the continuum level in the archival-high spectrum cannot be produced in a bicone without invoking an additional contribution from an absorption component. Thus, if a bicone is present, it must usually be weak, only appearing in 1993 due to a change in behavior perhaps associated with the unusually high continuum level. If we adopt this interpretation, then in terms of the reverberation model, the difference in response of the red and blue sides of the broad emission-lines between the archival and campaign spectra implies that the BLR is very extended in size and lies close to the line of sight.

One plausible model for the BLR is emission from clouds moving in a biconical outflow, which may or may not be relativistic (Orr & Browne 1982), and whose axis is aligned close to the line of sight. Alternatively, the BLR may be comprised of a spherically symmetric outflow, irradiated by an anisotropic continuum source, and whose strongest component lies close to the line of sight. Such a situation might arise if the continuum emission originates from the surface of an accretion disk with a low line of sight inclination (Netzer 1987; Wanders et al. 1995). In the bicone model a minimum distance of the gas producing the red C IV peak can be estimated by assuming the continuum increased to the campaign level early in 1993 February. If profile variations are caused by reverberation effects, then the lack of response for the red peak during the three-month campaign then implies a distance of the red emitting gas from the continuum source of at least 1.5 light-months.

If we assume that C IV remains responsive when the continuum increases, the weaker response in the line core is then consistent with a geometrically thick BLR in which the velocity *decreases* with increasing distance from the central ionizing continuum source. Conversely, it the clouds are unresponsive (i.e., saturated) in the C IV line (§ 3.2), a suggestion supported by the decline in EW with increasing continuum level, then the profile variations are consistent with a geometrically thick BLR in which the velocity *increases* with increasing distance from the central ionizing continuum source. For example, Figure 7 shows that at least in a qualitative sense, the low-state (*lower panel*) and high-state (*upper panel*) spectra can be modeled by emission from clouds moving radially outward in a biconical flow. For the model shown here, the clouds are confined to a biconical region with semi-opening angle $\omega = 30°$ and line of sight inclination $i = 60°$. The BLR is assumed to be spatially extended with a ratio of inner to outer radius, $R_{\rm in}/R_{\rm out} = 0.1$, while the velocity law is modeled as a Hubble-type flow [i.e., $v(r) \propto r$]. For the radial emissivity distribution [$\epsilon(r)$] we assume a simple power-law with radius such that $\epsilon(r) \propto r^{-3}$. In the high state the material is assumed to be tinuum is unusually strong. We have discussed one possibility, namely a biconical model in which the biconical emission component has greatly increased its relative contriubtion to the line profile in 1993.

Further higher-quality data are required to clearly distinguish between these possibilities. We are currently acquiring such data with the *Hubble Space Telescope*, and these data together with more detailed models will be presented in a future publication.

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